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# FINAL REPORT

# THE BEHAVIOUR OF FROZEN BACKFILL IN UNDERGROUND MINES

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SUPPLY and SERVICES CANADA

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## Executive Summary

Frozen tailings materials are not used at present in Canada for underground backfilling functions. The implications of using frozen tailings as underground backfill material in mines located in zones of permafrost are far reaching both from the view points of mine stability and disposal of tailings in the arctic regions.

This report was prepared under contract DSS-1SQ82-00151 between the Department of Supply and Services and Nantar Engineering of Kingston, Ontario, Canada.

Representative samples of tailings materials were obtained from three Canadian mines, namely: Chadbourne, Matagami and Denison Mines. On each tailings material, the following properties were measured to determine the nature of the materials used for the frozen tests: grannulometry, specific gravity of solid particles, bulk density, porosity and shape of particles.

The following tests were conducted on the frozen tailings materials:

a) determination of the optimum water content versus strength of frozen tailings - strength test results indicate that mixtures of 75% by weight solids, 25% water yield the highest instantaneous uniaxial compressive strengths: 7800 kPa

b) determination of the optimum pelletizing conditions for each tailings materials - results show that the tailings materials pelletize well with water contents ranging from 6% by weight for the Matagami tailings to 22.5% for the Denison tailings

c) determination of the short term strength of specimens 10 cm in diameter by 20 cm in length composed of frozen pellets with added water, and previously compressed under loads of 0, 450 and 900 kg to simulate the self-weight of columns of backfill materials in stopes

- results show that specimens without pre-consolidation loads exhibit only marginal short term strength: 144 to 317 kPa. - the highest short term strengths are obtained for specimens subjected to 900 kg of pre-consolidation load or an equivalent height of fill of 30 m: 1514 to 2803 kPa

The authors conclude that frozen tailings materials have definite possibilities as backfill for underground mines located in zones of permafrost. Additional long term behaviour testing along with in-situ tests are needed to confirm these preliminary tests and to enable use of the results in mine backfill stability analyses.

## 1.0 Introduction and Terms of Reference

Frozen tailings material has never been used to backfill underground openings in Canadian mines. At present only one Canadian mine, Polaris mine situated on Little Cornwallis Island, is investigating the use of frozen backfill. However, the Canadian North covers a very large territory and potentially contains a large number of mineral deposits. When combined with other areas of the world, the possibility of mining in permafrost zones is imminent. The understanding of concepts related to mining activities in sub-zero frozen ground materials is a matter of great importance.

The implications of using frozen tailings as underground backfill material are far reaching both from the point of view of mine stability and disposal of tailings in the arctic regions.

This report was prepared under contract DSS 1SQ82-00151 between the Department of Supply and Services and Nantar Engineering of Kingston, Ontario, Canada. Mr. M. Gyenge of the Canada Centre for Mineral and Energy Technology (CANMET) acted as Scientific Authority on the project.

The prime objective of the study was to determine the important physical and mechanical properties of frozen tailings materials.

Representative samples of tailings materials were obtained from: Chadbourne mine, a gold producer of the Noranda Group, and Matagami mine, a base metal producer of the Noranda Group; both of these mining operations are located in Northwestern Quebec. A third sample of tailings was obtained from Denison mine, a uranium producer located in Elliot Lake, Ontario.

On each tailings material, the following properties were measured to determine the nature of the material used for the frozen tests: grannulometry, specific gravity of

solids particles, bulk density, porosity and shape of particles.

The following tests were conducted on the frozen tailings materials:

a) determination of the optimum water content versus strength of frozen tailings
b) determination of the optimum pelletizing conditions for each tailings material: percentage of water
c) determination of the short term strength of specimens 10 cm in diameter by 20 cm in length composed of frozen pellets with added water and previously compressed under various loads to simulate the self-weight of columns of backfill in stopes

## 2.0 Determination of Tailings Properties

### 2.1 Grannulometry

The following general procedure was followed in conducting particle size analyses.

Samples, approximating 200 g of representative materials, were selected, dried and weighed. Wet screening tests were then implemented by initially preparing an oversize material retained on a 270 mesh sieve. The wet oversize fraction was dried, weighed and screened with appropriate sieves between 10 mesh and 400 mesh fractions.

The wet undersize material was allowed to settle and the water decanted; the slurry was dried and weighed. Wet sieving of the undersize through 270, 325 and 400 mesh sieves was then performed. The weight fractions and percentage fines distributions were determined for each of the sample batches selected. Based on a minimum of 3 runs for each tailings product, the results are presented in the curves of Figure 1.

The curves of Figure 1 indicate that the materials used for the tests have significantly different grannulometry.

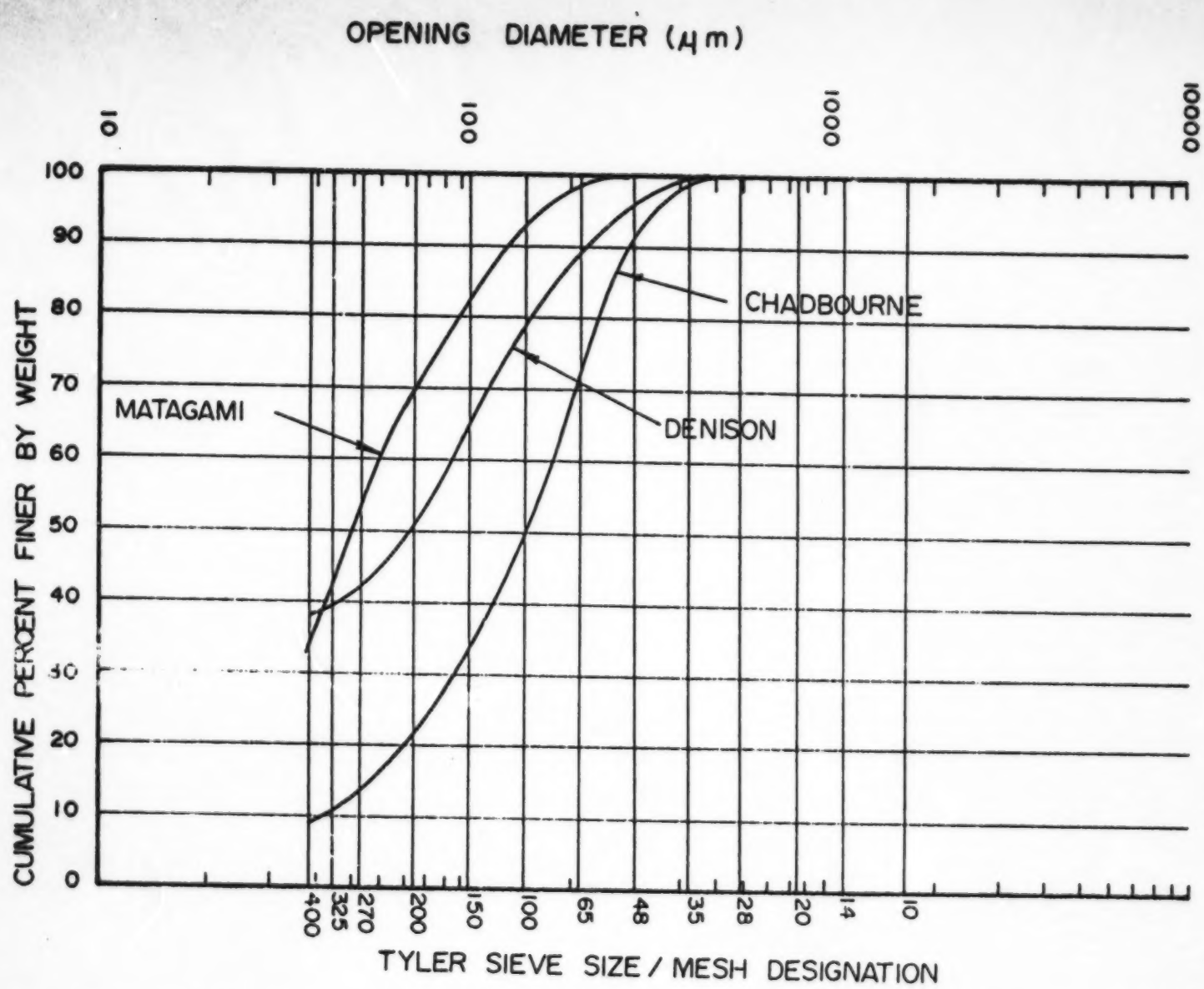



FIGURE 1 - SIZE DISTRIBUTION CURVES FOR DENISON, MATAGAMI AND CHADBOURNE TAILINGS

The Chadbourne tailings are the coarsest with 22% of the material smaller than 200 mesh. Denison tailings are 52% by weight finer than 200 mesh and the Matagami tailings are the finest with 69% finer than 200 mesh.

## 2.2 Specific Gravity of Solids, Bulk Densities and Porosity

The specific gravity of the solid constituents of the three tailings materials was determined in a helium/air pycnometer. The as received bulk density and dry bulk density were determined by weight known volumes of each material.

The porosity was determined according to the relationship.

$$n = 1 - \rho/\rho s$$

Where $\rho$ = dry bulk density

$\rho s$ = specific gravity of solids

Table 1 summarizes the values obtained from the three tailings materials tested.

## 2.3 Shape of Particles

The shape of the particles of solids making up the fill material is an important characteristic to record in this type of study. It is generally agreed that the strength of frozen fill develops from interparticle friction and particle interlocking. Grain shape is defined by a measure of the sharpness of the corners. The final grain shape of tailings material is the result of crushing, concentration and transportation to its final disposal site. Crushing creates highly angular particles and concentration and transportation will have the effects of smoothing out the corners of the particles. If the transportation distance is relatively short, the tailings particles will remain angular.

Photographs illustrating magnified views of tailings constituents at 100x magnification, for those scales

TABLE 1

Specific Gravity, Bulk Densities, and Porosity
for
Denison, Chadbourne and Matagami Tailings

| | Denison | Chadbourne | Matagami |
|---|---|---|---|
| Specific Gravity of solids(g/cm3) | 2.97 | 2.95 | 3.72 |
| Dry Bulk Density | 1.33 | 1.70 | 1.79 |
| Moist Bulk Density | 1.93 | 2.22 | 2.85 |
| Moisture Content | 27.3% | 16.9% | 11.2% |
| Porosity (dry) | 55.2 | 42.4 | 51.9 |

indicated, were taken of the three mine tailings. Figure 2 illustrates the photographic views. It can be observed that the particles in all cases exhibit sharp corners; it can also be observed that the Chadbourne and Denison products are much coarser than the Matagami tailings, as indicated by sieve size analyses.

## 3.0 Description of Tests Performed and Results

### 3.1 Short Term Compressive Strength Versus Water Content

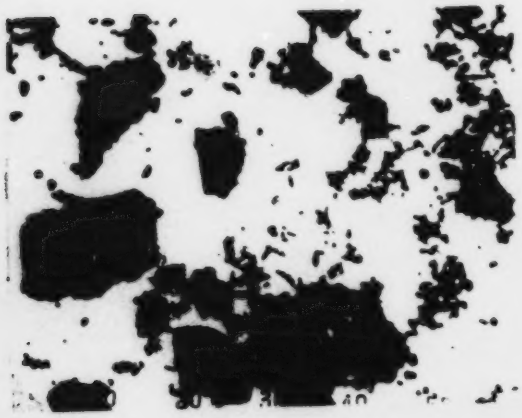
The strength of frozen soils develops from cohesion, interparticle friction and particle interlocking (1). Cohesive forces are attributed to adhesion between particles and to ice bonds in the fill voids. At low solids concentrations (ice-rich soils), the strength and mechanical behaviour will approximate that of ice. At high solids concentrations (ice-poor soils) interparticle friction and dilatency play a major part in determining the soil strength. The great difference in strength between frozen and unfrozen soils is derived from the ice components.

For a typical sand mixture, some researchers (2,3) have measured that for low value fractions of sand (less than 40% sand by volume), the increase in strength is low. When a critical volume fraction of sand, about 42%, is reached, a rapid increase in strength is observed. At this point, these authors theorize, friction between sand particles and dilatency begin to contribute to the strength of the frozen sand.

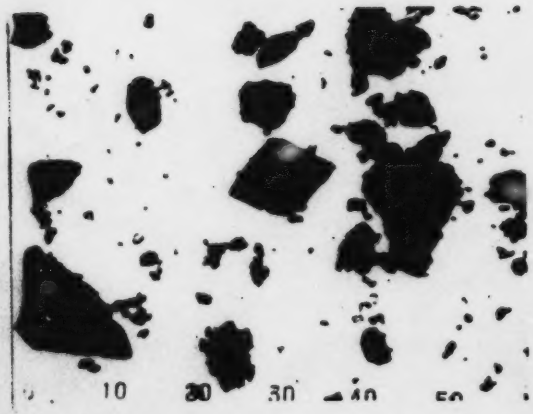
The tests described in this section represent an attempt to determine the optimum constituents ratio for the Denison, Chadbourne and Matagami tailings products.

The authors chose to experiment with five solids/water ratios as follows: 90/10, 85/15, 80/20, 75/25 and 70/30. These ratios should be interpreted as 90 g of solids to 10 g

A) MATAGAMI TAILINGS



B) DENISON TAILINGS



C) CHADBOURNE TAILINGS

0 100 μm

FIGURE 2 - MICROSCOPE PHOTOGRAPH OF TAILINGS

of water, etc. The water contents are expressed as is customary in the mining industry; 10%, 15%, 20%, 25% and 30% respectively.

The dry tailings materials were weighed and mixed with the required amounts of water to produce slurry mixtures which were subsequently poured into 38 mm ϕ by 76 mm PVC tubing and placed in a cold room for a period of 48 hours at a temperature of -12°C. The specimens were then tested on a Material Testing System (MTS) servo-controlled compression loading frame shown in Figure 3. The unit has a peak loading capacity of 100 tonnes with a maximum load resolution in the order of ± 10 kg. The rate of loading was maintained constant at a rate of 0.07 MPa/sec. Each mixture was tested with a replication of six and the results were averaged. The results of the short term peak uniaxial compressive strength tests are given in Table 2.

Based on the unconfined compression tests performed, maximum strength behaviour was found to be exhibited by frozen slurry materials constituted by approximately 25% water by weight.

## 3.2 Pelletizing Tests

Backfill materials that can be handled without undue difficulties represent a marked advantage for a mining operation. The concept of pelletizing the tailings material and subsequently allowing these pellets to be frozen by the naturally cold ambient air offers a marked cost advantage over other means of handling and freezing of the tailings product.

Pelletizing of concentrates with similar grannulometry as the tailings materials used for this study is done routinely in the mineral industry.

For the purpose of this study, the optimum water content of the pellets was set at approximately 25% by weight. Several pelletizing tests were therefore done with

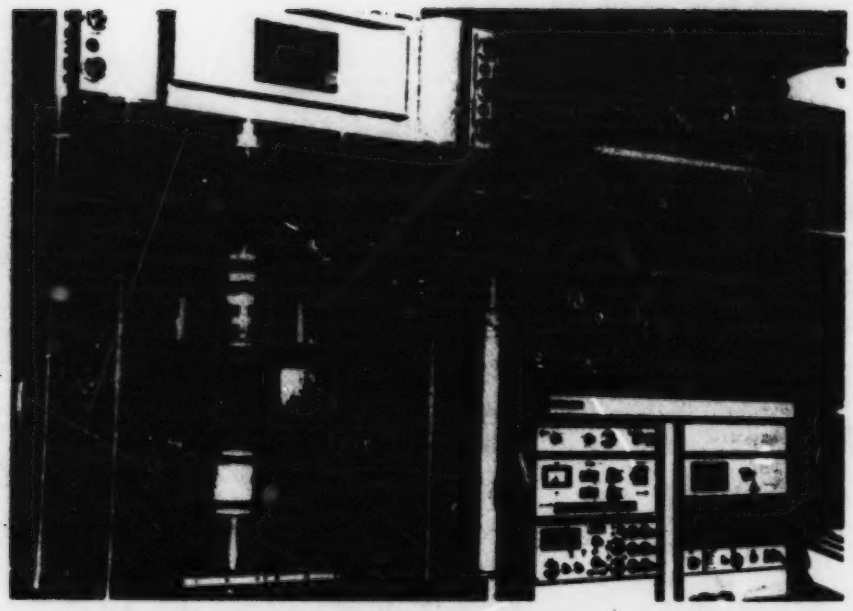


FIGURE 3 - MTS COMPRESSION LOADING FRAME

## TABLE 2

### Short Term Peak Compressive Strength

| Type of Material | Denison | Chadbourne | Matagami |
|---|---|---|---|
| | (Peak uniaxial compressive strength in kPa) | | |
| 90/10 (solids/water) | 502 | 2593 | 1183 |
| 85/15 (solids/water) | 2009 | 4382 | 3212 |
| 80/20 (solids/water) | 2600 | 6946 | 3976 |
| 75/25 (solids/water) | 6769 | 8626 | 8014 |
| 70/30 (solids/water) | 5102 | 5190 | 3973 |

Notes to Table 2:

i) all tests replicated 6 times
ii) the numbers shown are averages
iii) tests performed on 38 mm ϕ by 76 mm specimens
iv) all samples failed under constant rate of loading of 0.07 MPa/sec.
v) the temperature of the specimens at time of testing was -12°C

the three tailings materials to assess the type of pellets that could be generated.

The pelletizing tests were conducted with a Dravo Laboratory Model Pelletizing disk, 35 cm in diameter, powered by a ¼ h.p. vari-drive motor. The slope of the disk was maintained at 60° from the horizontal and the speed at 16 rpm. Figure 4 illustrates the pelletizing equipment.

From the pelletizing tests it was found that pellets of various sizes could be formed using total tailings from the three mines without great difficulties.

For each of the materials available, pellet size distribution, moisture content range and frozen pellet failure load parameters were determined.

Figure 5 shows the size distribution of the pellets formed from each tailings material. Pellets were prepared at various moisture contents up to the point at which free water was observed to collect about, but not be retained by, the pellets. The upper moisture limits are for such fabricated pellets. It has been possible to fabricate pellets with moisture contents varying from 6%, for the Matagami tailings, to 22.5% for the Denison tailings. Pellets, within the moisture content ranges listed were observed to be firm and could be handled readily. Table 3 gives the moisture content ranges for each tailings materials.

TABLE 3

Moisture Content of Pellets

| Mine | % Water by Weight |
|---|---|
| Matagami | 6 to 14 |
| Chadbourne | 14 to 17 |
| Denison | 11 to 22.5 |

FIGURE 4- PELLETIZING EQUIPMENT

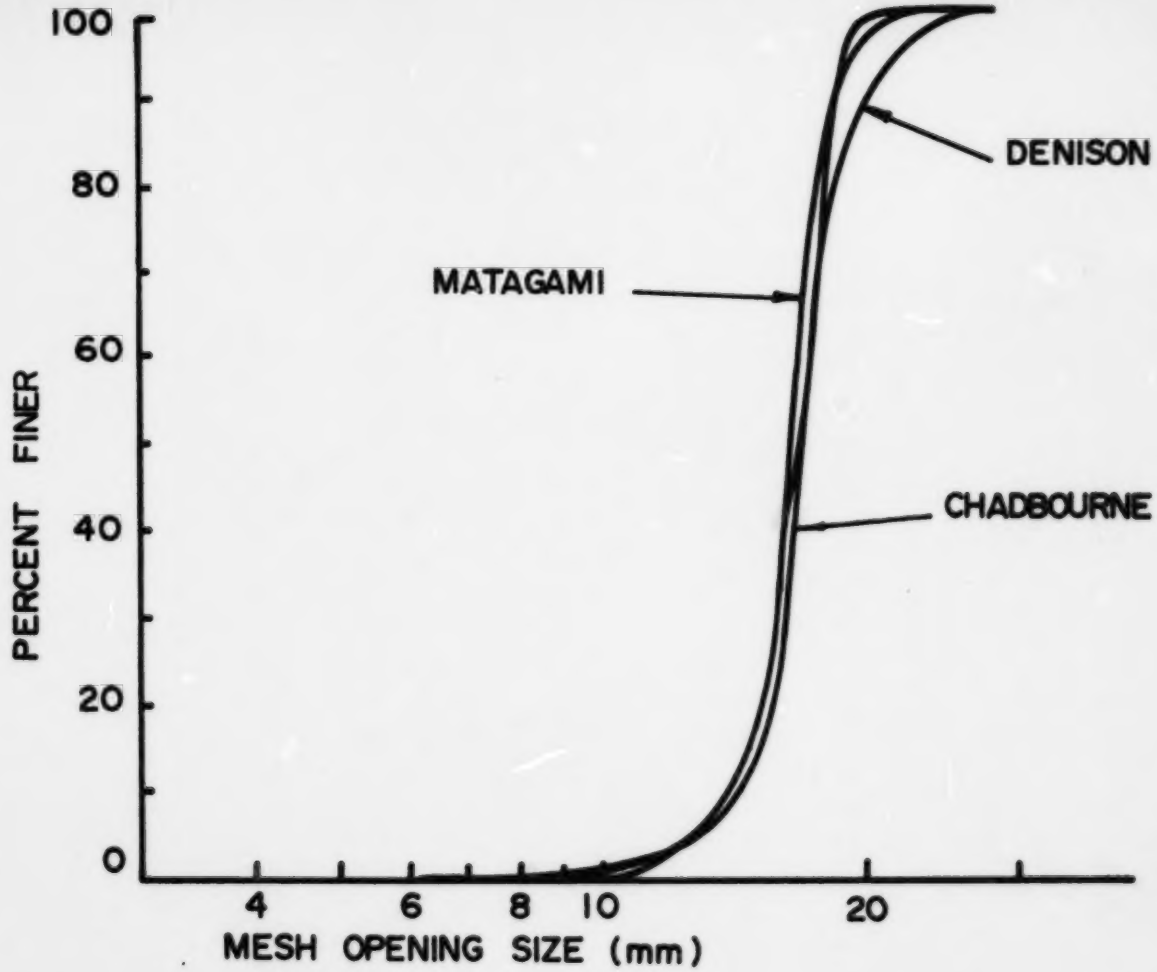



FIGURE 5 - SIZE DISTRIBUTION OF PELLETIZED TAILINGS

For the purpose of fabricating large cylinders of frozen pellets to be tested for compressive strength, the authors decided to fabricate pellets with the highest moisture content possible for each material.

The strength of individual pellets was also tested using a Brazilian Indirect Tensile Strength frame. The pellets frozen to a temperature of -12°C were observed to demonstrate remarkable point load resistance: as much as 114 kg was required to break a 2 cm diameter pellet. Figure 6 shows graphs illustrating the point load resistance of pellets versus size.

To simulate the effects of free fall impact conditions, as would be encountered when pellets are discharged down a fill raise, drop tests were conducted using frozen pellets, from heights of 3 m and 35 m. From the lower drop heights, pellets were observed to remain intact as they impacted a concrete floor. When dropped from a height of 35 m, severe damage to the pellets occured upon impact. This latter aspect would be beneficial, if such frozen pellets were used as the backfill medium in a mine.

### 3.3 Short Term Compressive Strength Tests On Cylinders of Frozen Pellets

For these tests, the pellets as produced on the pelletizing disk were frozen at -12°C and introduced into 10 cm diameter by 20 cm long PVC cylinder tubing. Small quantities of water applied with an atomizer were added to the pellets as they were introduced into the molds. Sufficient quantities of water were added to bring the total water content to approximately 20% by weight.

Three series of tests were performed on the frozen pellet specimens:

a) no superincumbent load was applied to the cylinders of pellets. The cylinders (replication of three) of each

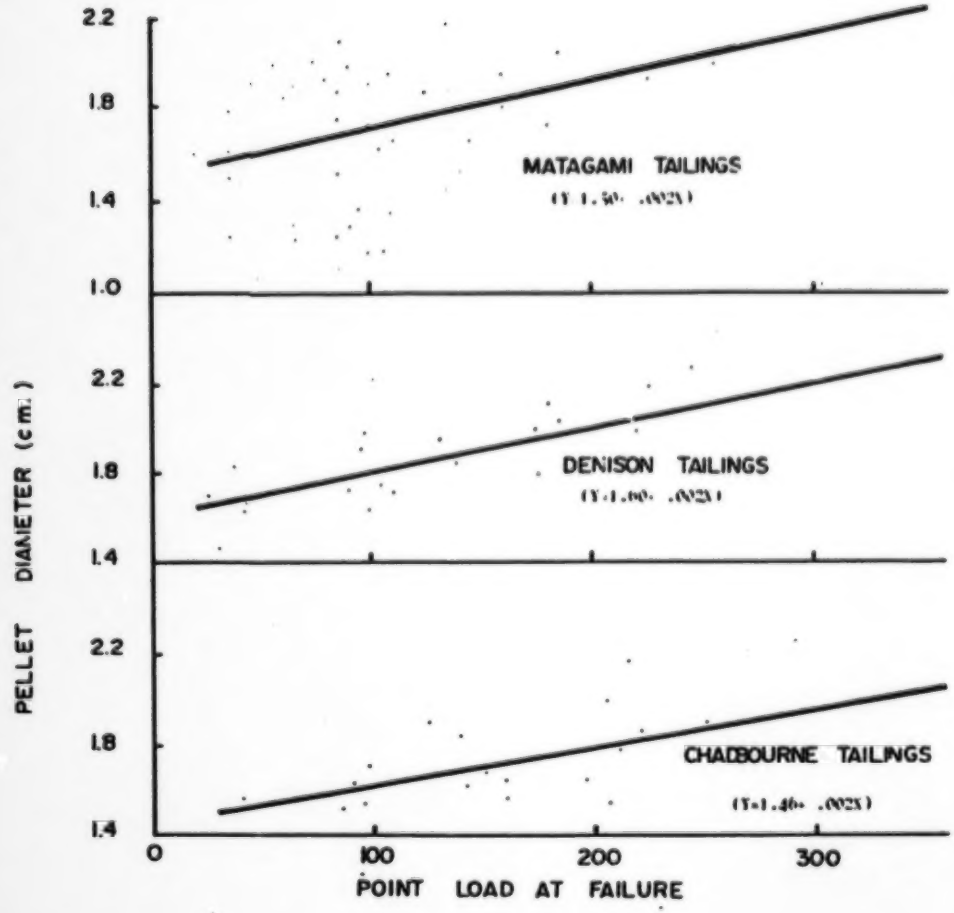



FIGURE 6 - POINT LOAD AT FAILURE FOR FROZEN BACKFILL PELLETS

type of tailings material were re-introduced in the cold chamber (-12°C) for a period of ten days before conducting compressibility and compressive strength measurements

b) 450 kg of consolidation load was applied to the cylinders before storing in the cold room for ten days

c) 900 kg of consolidation load was applied to the cylinders before storing in the cold room for ten days

Photographs taken during the testing operation illustrates remarkably well the nature of the "frozen-pellet-backfill material" in a state of non-consolidation (Figure 7), with a pre-consolidation load of 450 kg applied (this load is equivalent to a height of fill of 15 m, Figure 8) and finally with a pre-consolidation load of 900 kg (Figure 9).

The results of the short term uniaxial compression strength tests on cylinders of frozen pellets with various pre-consolidation loads applied to the specimens are given in Table 4.

## 4.0 Discussion and Conclusions

The work conducted under the terms of this research agreement indicates that frozen tailings exhibit remarkable structural properties. A companion between unfrozen tailings materials, or unfrozen cemented mine backfill and frozen tailings, will exemplify this statement. Ranges of unconfined compressive strength values for cemented backfill are as follows (4):

FIGURE 7 - CHADBOURNE FROZEN PELLETS - UNCONSOLIDATED

FIGURE 8 - CHADBOURNE FROZEN PELLETS - 1000 POUNDS (450 kg) OF CONSOLIDATION LOAD

FIGURE 9 - DENISON FROZEN PELLETS
2000 POUNDS (900 kg)
OF CONSOLIDATION LOAD

| Sand-cement ratio | Ranges of Comp. Strength (psi) | (kPa) |
|---|---|---|
| 40:1 | 16-40 | 109-272 |
| 30:1 | 40-70 | 272-476 |
| 20:1 | 70-100 | 476-680 |
| 10:1 | 200 | 1361 |
| 5:1 | 500-600 | 3401-4082 |
| 2:1 | 2,500 | 17,000 |

As can be observed from Table 2, a mixture of 75% tailings and 25% by weight water, has a uniaxial compressive strength of nearly double the non-frozen backfill at 5:1 sand-cement ratio. (The average strength of the three frozen tailings materials is 7,803 kPa). When the compressive strengths of cemented backfill are compared with the frozen backfill composed of pellets which has been consolidated to 900 kPa, (Table 4), it is interesting to note that the short term uniaxial compressive strength of the Denison, Chadbourne and Matagami materials all exhibit strengths higher than a non-frozen fill with a ratio of sand-cement of 10:1. Based on the short term strength of frozen tailings materials, it is realistic to envisage the use of such backfill materials in mines located in zones of permafrost. The authors envisage the following scenario where frozen pellets fabricated with mill tailings could be used in a mine located in a zone of permafrost:

a) the tailings originating from the mill would be dewatered to the required moisture content
b) the dewatered tailings would be pelletized on a balling disk or other pelletizing equipment
c) the pellets would be allowed to freeze in the cold arctic air
d) the pellets could then be stored on surface or hauled to the mine and introduced underground via a surface dump point - the surface handling of the frozen pellets could be done with a front end loader and truck

TABLE 4

## UNCONFINED COMPRESSION FAILURE PARAMETERS

| Pre-consolidation Loads (kg) | Bulk Density (g/cm3) | Failure Stress (kPa) | Modulus of Compression (kPa/%strain) |
|---|---|---|---|
| Denison | | | |
| 0 | 1.20 | 144 | 212 |
| 450 | 1.32 | 583 | 941 |
| 900 | 1.46 | 2616 | 1207 |
| Chadbourne | | | |
| 0 | 1.26 | 220 | 731 |
| 450 | 1.32 | 739 | 1495 |
| 900 | 1.43 | 1514 | 2410 |
| Matagami | | | |
| 0 | 1.68 | 317 | 170 |
| 450 | 1.84 | 507 | 884 |
| 900 | 2.05 | 2803 | 1990 |

Notes to Table 4:

i) all tests replicated three times
ii) the bulk density and failure stress numbers are averages
iii) tests performed on 10 cm Ø by 20 cm specimens
iv) all samples failed under constant rate of loading of 0.07 MPa/sec.
v) the temperature of the specimens at time of testing was -12°C

combination or feeder/conveyor belt arrangement - the scenario is schematically represented in Figure 10 - once in the state of frozen pellets, the fill material would lend itself to easy handling and this aspect could make such a backfilling operation of underground mines very attractive

The authors are of the opinion that the type of backfill material tested on a limited basis during the course of this research project has definite applications in mines located in zones of permafrost and that with further laboratory and in-situ test work, such backfill can be utilized underground.

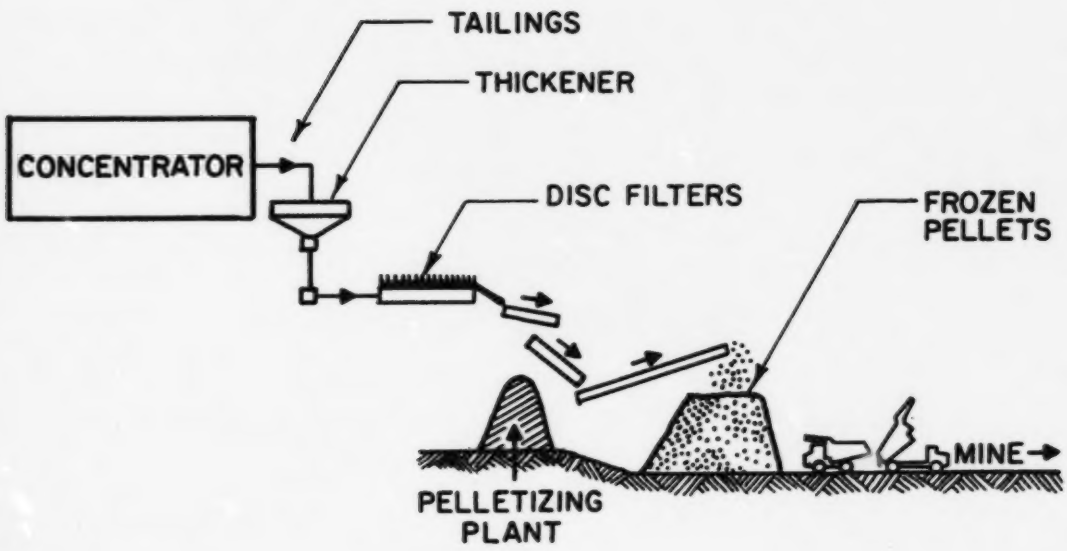



FIGURE 10 - SCHEMATIC REPRESENTATION OF FROZEN BACKFILL PREPARATION PLANT

## 5.0 Future Research Activities

The strength of frozen materials (soil, backfill, etc.) may take on different meaning depending on the engineering situation. Both the concepts of rupture and excessive deformation need to be considered. The functions usually required to be performed by the backfill material in underground mines may be summarized as:

a) working floors; such as in cut and fill stopes
b) stope wall support; for cut and fill and delayed fill stopes
c) self-support when backfill is exposed on one face; during pillar recovery phases

For fill functions such as working floors, the short term response of the frozen fill is the dominant concern. For the other fill functions, the long term deformation response of the frozen fill or creep is of interest.

The present research project did not address the long term behaviour of frozen backfill; it is recommended, considering the encouraging results obtained with the short term strength tests, that a series of creep tests be conducted to investigate the time dependent deformation properties of frozen backfill. This data could then be used to analyse the stability of backfill free faces composed of frozen backfill.

Acknowledgements

The authors are grateful to the Department of Supply and Services, Canada for the opportunity to work on this research project. Sincere thanks are extended to Mr. M. Gyenge of CANMET for his continuous assistance on all aspects of this study.

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